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Towards An Understanding of Adult Judgments of Synergistic Health Benefits
Abstract

Objective: Numerous scientific studies show that certain combinations of dietary and/or lifestyle factors produce health benefits which are greater than the sum of the benefits associated with each factor alone. To address an existing knowledge gap, we assessed the extent to which individuals understand that certain combinations present these ‘synergistic health benefits’.

Design: Health benefit judgments were obtained from lay adults for a range of dietary and/or lifestyle combinations that have been found to present synergistic benefits. Association between these judgments and socio-cognitive characteristics such as numeracy, education and health interest were examined.

Methods: 352 Swiss adults were presented with a description of one of eight synergistically beneficial combinations. Each participant provided a categorical benefit judgment (i.e., sub-additive, additive or synergistic) for the combination and explained the cognitive reasoning underlying their judgment. Participants completed measures of numeracy and health interest.

Results: The proportion of combinations judged to present a synergistic benefit was modest for ‘macro-level’ combinations (e.g., diet and exercise), but low for ‘micro-level’ combinations (e.g., two phytochemicals). Cognitive reasoning data showed that a higher proportion of judgments for micro-level (cf. macro-level) combinations were based on greater subjective epistemic uncertainty. Higher interest in health was associated with a better understanding of synergistic benefits, but numeracy and education level were not.

Conclusions: There is considerable scope to improve the extent to which lay adults understand that specific combination of diet and lifestyle behaviours can synergistically benefit their health. Our results enable us to make informed recommendations for public health interventions.
**Keywords:** diet, exercise, health benefits, judgment, synergistic
An important concept to recently emerge in the health, sports science and nutrition literature is that of ‘synergistic health benefits’ (e.g., Jacobs, Gross, & Tapsell, 2009; Liu, 2003; Mitchell, 2013; Pretty, Peacock, Sellens, & Griffin, 2005; Wang, Meckling, Marcone, Kakuda, & Tsao, 2011). This concept refers to the notion that the health benefits associated with certain combinations of dietary and/or lifestyle factors are greater than the sum of the benefits associated with each factor individually. For example, numerous studies have found that specific food combinations (e.g., fish and garlic, tomatoes and broccoli, etc.) interact to produce a synergistic increase in the processes (e.g., antioxidation) that fight non-communicable diseases such as cancer and heart disease (e.g., Canene-Adams et al., 2007; Manikandan et al., 2012; Ninfali, Mea, Giorgini, Rocchi, & Bacchiocca, 2005; Thompson & Ward, 2006). Other studies show that combining exercise with natural, green (cf. non-natural, urban) environments can synergistically improve mental (Mitchell, 2013) and physical health (Blair et al., 1996, and Pretty et al., 2005). Furthermore, preliminary research suggests that synergies between food combinations such as nuts and berries can enhance cognitive performance and could be utilized as an adjunct therapy for aged-related neurodegenerative disorders (Pribis & Shukitt-Hale, 2014). Several studies have already identified many of the combinations of phytochemicals (bioactive non-nutrient compounds found in many plant-based foods) that interact to elicit specific food-related synergistic health benefits (e.g., Liu, 2003; Pignatelli et al., 2000; Tang et al., 2010; Wang et al., 2011).

Despite the accumulation of evidence concerning the concept of synergistic health benefits and the potential for this knowledge to be utilized to improve public health, there is an absence of studies that have examined the extent to which lay individuals understand the concept. While many national and international public health campaigns (e.g., ‘five-a-day’, ‘change4life’, ‘Healthy China 2020’, etc.) already encourage people to consume multiple food types and/or participate in a range of sports and exercise activities (Hancock, 2009; Hu,
Liu, & Willett, 2011; Naska et al., 2000), these campaigns have not focused on explaining the potential to achieve synergistic health benefits from specific combinations. The importance of being aware of which combinations elicit synergistic benefits is highlighted by studies showing that some seemingly healthy combinations interact to produce sub-additive effects (i.e., the benefits are less than the sum of the benefits attributable to each constituent; e.g., Liu, 2003; Pretty et al. 2005). For example, Wang et al. (2011) found that from a total of 55 different pairwise combinations of fruit, vegetables and legumes, 25% of the combinations produced antagonistic/sub-additive effects on the antioxidant capabilities of the constituents.

To support effective health behaviour change it is important to gain an understanding of individual’s perceptions of health-impairing (i.e., health risks) and health protective (i.e. health benefits) behaviours. Research on health-related decision making has shown that individuals rarely process health information on risks and benefits in a systematic and veridical manner. Instead, individuals often process such information in a way that can best fit with how one sees oneself (Morrison & Bennett, 2012) or using cognitive heuristics that can, in some instances, lead to biased judgments and decisions (Peters, McCaul, Stefanek, & Nelson, 2006). For example, information processing can be defensive and self-affirming (Good & Abraham, 2007; Wright, 2010) or subject to inaccurate perceptions of risks and susceptibility (unrealistic optimism; Weinstein, 1983), which, consequently, can hinder the effectiveness of health communications. Hence, from a public health perspective, it is important to understand whether people arrive at accurate evaluations of the health benefits that are associated with certain combinations of health-related behaviours.

There is an absence of studies that have examined the extent to which individuals are aware of the concept of synergistic health benefits or of the combinations that elicit these benefits. Nonetheless, potential insights into these phenomena can be drawn from four related strands of literature. First, several studies have examined individual’s understanding of the
concept of synergistic health risks (the risk attributable to the combination is greater than the sum of the risk attributable to each constituent; e.g., Dawson, Johnson, & Luke, 2012a; French, Gayton, Burton, Thorogood, & Marteau, 2002; Hampson, Andrews, Lee, Lichtenstein, & Barckley, 2000). These studies have often found relatively low levels of awareness of the synergistic health risks attributable to less “familiar” combinations (e.g., drug-drug combinations such as aspirin and clopidogrel), but relatively high levels of awareness of the synergistic risks associated with more “familiar” combinations (e.g., alcohol and driving) (Dawson, Johnson & Luke, 2014, p. 7; Hampson, Andrews, Barckley, Lee, & Lichtenstein, 2003). This suggests that certain combinations of factors can become familiar, whether through public awareness campaigns or targeted interventions, as being harmful and individuals often infer that such combinations elicit synergistic effects. This raises the possibility that individuals draw such inferences about combinations that are reported to present health benefits (e.g., ‘exercise and a healthy diet’ or ‘fruits and vegetables’). The possibility that individuals infer that more familiar health-enhancing/protecting combinations elicit synergistic benefits remains untested.

Second, to develop a framework for understanding the various pathways by which food synergies operate, nutritionists Jacobs and Steffen (2003) created a five-level hierarchical taxonomy of food synergies. Specifically, they categorized the highest level of food synergy as occurring in ‘dietary patterns’ (e.g., Western diet, prudent diet, etc.) followed by ‘food groups’ (e.g., dairy, fruit, vegetables, etc.), then ‘whole grains’ (e.g., whole wheat, brown rice, etc.), ‘whole wheats’ (e.g., germ, endosperm, etc.) and, at the lowest level, ‘phytochemicals’ (e.g., lycopene, quercetin, etc.). By taxonomizing synergistic benefits in this way, Jacobs and Steffen have alluded to the possibility that lay individuals may also identify that synergistic benefits can be attributed to interactions between constituent factors at different levels. As outlined above, it is possible that people may be more inclined to infer
that familiar combinations at a high level in a synergies hierarchy (e.g., diet and exercise) elicit synergistic benefits. By contrast, people may be less likely to infer that combinations featured at the lower end of the hierarchy (e.g., phytochemicals) elicit synergistic benefits because these micro-level food units may be less familiar (Lambert, 2001; Scheerens, 2001). Consequently, individuals may experience greater epistemic uncertainty (i.e., uncertainty due to incomplete knowledge) about the foods which contain lower level bioactive compounds and with the potential effects of combining these compounds.

Third, research shows that individuals with a higher level of education or interest in personal health typically engage in healthier eating practices and lifestyle activities (e.g., Dutta-Bergman, 2004; Ross & Wu, 1995). Hence, it is possible that individuals with a higher level of education or ‘health interest’ may also have a greater understanding of the concept of synergistic health benefits. For example, individuals who have undertaken courses at further/higher educational institutions may have learned about statistical interactions between multiple factors (Bradstreet, 1996; Fields et al., 2009) and, therefore, may be more open to the plausibility of foods and/or physical activities interacting synergistically. Similarly, individuals with a strong interest in personal health often proactively seek out health-related information (Lambert & Loiselle, 2007) and, consequently, may have encountered information in specialist books (e.g., Servan-Schreiber, 2011) or websites (e.g., Men’s Health, 2014) about synergistic health benefits.

Finally, a further factor that might influence comprehension of the synergistic benefits concept is numeracy: the ability to understand and process statistical and mathematical concepts (Peters et al., 2006; Wright, Whitwell, Takeichi, Hankins, & Marteau, 2009). Given that the formal identification of a synergy typically requires a numerical calculation (i.e., adding the effect of each constituent and then subtracting this from the combined effect to determine which is greater) it is possible that lower numerate individuals may be less adept at
understanding the concept of synergistic benefits. However, a study by Dawson et al. (2013) found that lower and higher numerate individuals were equally able to understand the concept of synergistic health risks. Dawson et al. suggested that whether individuals understand that certain factor combinations are synergistic does not appear to be moderated by numeracy but, rather, by access to effective learning opportunities about the effects of combining those factors. This further supports the above argument that education and health-information seeking behaviors may influence an individual’s understanding of synergistic benefits. By contrast, numerical skills may be much less important.

The absence of research examining lay understanding of synergistic health benefits makes it difficult to determine the extent to which individuals are suitably equipped to make effective choices about combining dietary and lifestyle behaviours to protect or enhance their health. Moreover, this lack of evidence diminishes the capacity to develop effective interventions and educational materials about synergistic benefits that are tailored to the target audience. Hence, we conducted a study to assess the extent to which lay individuals understand that certain combinations of factors can elicit synergistic health benefits. Based on the above inferences drawn from the extant literature, our study tested the following hypotheses:

1. A greater proportion of higher (cf. lower) level combinations will be judged to present synergistic benefits
2. The proportion of combinations judged to present synergistic benefits will be greatest among individuals with a higher (cf. lower) interest in personal health
3. There will be greater epistemic uncertainty about the benefits attributable to lower (cf. higher) level combinations
4. The proportion of combinations judged to present synergistic benefits will be greatest among individuals with a higher (cf. lower) level of education
5. Numeracy will not affect whether individuals judge that combinations present synergistic benefits

**Method**

*Overview:* Drawing on Jacobs and Steffen’s (2003) concept of taxonomizing synergistic combinations into different hierarchical levels, we assessed participant’s judgments of the health benefits attributable to various food and/or exercise combinations at four different levels (ranging from ‘macro-level’ synergistic interactions between exercise behaviours and dietary patterns, through to ‘micro-level’ synergistic interactions between specific phytochemicals). We assessed whether the judgments were moderated by the individual’s level of education, numeracy, and health interest. We also gathered data concerning the cognitive reasoning that individuals employed when formulating their judgments. This data was obtained to provide preliminary insights into how subjective epistemic uncertainty may have influenced the individual’s judgments at each of the four levels.

*Participants.* The Swiss health system is highly efficient, reflected in high levels of patient satisfaction and one of the longest life expectancies in the world (OECD/WHO, 2011). A central feature of the Swiss health system is its mandatory health insurance which, simultaneously, fosters personal responsibility (e.g. by individual co-payments). Switzerland also provides high standards of education. Hence, we recruited a Swiss sample (*N* = 352) to increase the likelihood that our participant’s awareness of synergistic health benefits might be sufficiently high to be detectible in our study. Participants were recruited via a professional online panel provider that assured sampling quality by carefully selecting panellists and providing a proportionate incentive. Each participant provided informed consent and was paid €0.50. The following criteria were applied: participants must be residents of Switzerland and 18-69 years of age and the sample must have an equal distribution of men and women. Participation was possible until the targeted number of 175 men and 175 women had been
reached. Participants’ mean age was $M = 43$ ($SD = 13$) and was therefore representative of the Swiss Public: According of the Swiss Federal Statistical Office (BFS), the average age of the adult Swiss population between 18-69 years of age is 43 years (BFS, 2013). Self-reported education levels ranged from primary and lower secondary school (6.8%, $n = 24$), upper secondary vocational school / university preparation school (71.2%, $n = 251$) to college or university (21.9%, $n = 77$). Levels of education among participants were also representative of the Swiss public (BFS, 2013).

**Design.** The between-subject design consisted of four conditions (synergy level: highest, higher-middle, lower-middle, lowest) and two different scenarios were developed for each synergy level (i.e., eight scenarios in total). For the highest synergy level, the scenarios depicted combinations of factors that related to holistic lifestyle behaviours: (1) participating in regular physical exercise and eating a nutrient-rich diet, or (2) participating in regular physical exercise and regularly spending time in pleasant, natural environments. Higher-middle synergy level scenarios featured food group combinations: (1) regularly eating a variety of fruits and regularly eating a variety of vegetables, or (2) regularly eating a variety of fruits and regularly eating a variety of wholemeal foods. Lower middle synergy levels described combinations of specific foods: (1) regularly drinking green tea and regularly eating foods containing the spice turmeric, or (2) regularly eating tomatoes and regularly eating broccoli. The lowest synergy level scenarios described phytochemical combinations: (1) regularly eating foods that contain the bioactive compound quercetin and regularly eating foods containing the bioactive compound Epigallocatechin gallate (EGCG), or (2) regularly eating foods that contain the bioactive compound resveratrol and eating regularly eating foods containing the bioactive compound genistein. These eight combinations were specifically selected because the associated synergistic benefit had been identified in more than one study which, therefore, served to (a) ensure that the evidence for the reported
synergy was relatively robust and (b) minimise the possibility that any participants who might be aware of the literature in this field would judge the benefit as non-synergistic based on a belief that the extant evidence of a synergistic benefit was inconclusive. Table 1 summarises the hierarchical structure of the eight synergistically beneficial combinations and details the source of the empirical evidence for these synergies. The dependent variable was the participant’s subjective benefit judgment for each combination (sub-additive, additive, or synergistic).

[Insert Table 1 about here]

Materials and Procedure. The study was administered online and preceded two smaller unrelated questionnaires. Participants were instructed to complete the questions in isolation and not to consult any materials or persons. Participants were randomly presented with one of the eight synergistic benefit scenarios. Consistent with the design of materials employed by Dawson et al. (2014), participants first read a short two-sentence paragraph. The first sentence stated that research evidence showed that a specific single factor (e.g. regularly eating a variety of fruits) had a positive influence on health, because it increases the likelihood of not suffering from life-threatening health problems, such as cancer. The second sentence stated that research evidence showed that a different factor (e.g. regularly eating a variety of vegetables) also had a positive influence on health. After the first paragraph, participants were instructed to consider the positive influence that both factors would have on the likelihood of staying healthy. Participants were asked to state, using a multiple-choice response format, whether they judged this likelihood to be less than, equal to or more than the likelihood for an individual exposed to only the first factor added to the likelihood for an individual exposed to only the second factor. The answer to this question was the dependent variable; choosing less than, equal to or more than represented sub-additive, additive, or synergistic judgments, respectively. This type of categorical response format has previously
demonstrated validity and reliability in studies on judgments of synergistic risks (Condit & Shen, 2011; Dawson et al., 2014).

Participants were asked about the reasons for their judgment: different options were presented and participants were asked to select the option that best represented their reasoning. These options were developed according to the most common lines of reasoning found in other studies on judgments of synergies (Dawson, Johnson, and Luke, 2012b). More precisely, when participants chose “more than”, five options were subsequently presented. Three of the five options presented different forms of reasoning as to why the combination would elicit a synergistic benefit (e.g., “I think that when regularly eating a variety of fruits combined with regularly eating a variety of vegetables, these two foods interact and this causes a further increase in the overall health benefits of … both foods / regularly eating a variety of fruits / regularly eating a variety of vegetables”). One of the other options related to using an information source (e.g., “I obtained my knowledge about the combination from an information source [e.g., media, educational course, doctor, friend, etc.] and I used this knowledge to arrive at the answer”) and one was indicative of guessing (“I was not sure what the answer would be, so I selected one of the three options at random”). When participants chose the answer “equal to” they could select between three options: one that expressed reasoning that the benefits would be additive (“I think that regularly eating both fruits and vegetables would not cause the separate health benefits of either food to be increased or decreased, but to add together”), one that indicated the use of an information source, or an option that expressed guessing (wording for these two options was the same as above). If participants chose “less than”, they could select between five different options: three different forms of reasoning as to why the benefit would be sub-additive (e.g., “I think that when regularly eating a variety of fruits is combined with regularly eating a variety of vegetables, these two foods interact and this causes a decrease in the overall health benefits
of … both foods / of regularly eating a variety of fruits / of regularly eating a variety of vegetables”), one option that indicated the use of an information source, and one that expressed guessing.

Furthermore, participants responded to four items to capture the extent of their interest in health-related issues (e.g., “How often do you read books, magazines or newspaper articles on nutrition?”). Responses were given on a 4-point scale and averaged to achieve a scale score (Cronbach’s $\alpha = .82$). Numeracy was assessed using the Subjective Numeracy Scale (Fagerlin, Zikmund-Fisher et al., 2007), which assesses self-reported numeracy skills (e.g., “How good are you at working with fractions?”) on a 6-point scale. The scale score represented the mean response to all eight items (Cronbach’s $\alpha = .83$).

Statistical Analysis and Data Preparation. Analysis was conducted using hierarchical loglinear analyses, cross-tabulations and chi-square ($\chi^2$) tests. Initial inspection of the judgment data identified that the test assumptions for a three-way loglinear analysis had not been met because the proportion of cells with an expected count of 5 or less was greater than 20%. To overcome this, the ‘sub-additive’ and ‘additive’ categories were collapsed into a single ‘non-synergistic’ category (Field, 2013, p. 735). As a result of this transformation, the ‘benefit judgment’ variable had two categories (‘synergistic’ and ‘non-synergistic’) and the data met the test assumptions for three-way analysis. The practice of collapsing categories in this manner is commonly employed hierarchical loglinear analysis (e.g., Dawson et al., 2014, Fairclough, Boddy, Hackett, and Stratton, 2009). To further facilitate the tests, the health interest (HI), education level (EL) and numeracy variables were converted to dichotomous categorical variables as described below.

The mean HI score was 2.22 ($SD = 0.60$, $Md = 2.00$). Participants were split into two groups based on the median score: 50.3% ($n = 177$) of participants with a HI score of 2.00 and less were classified as lower HI, and 49.7% ($n = 175$) of participants with a HI score of
2.25 and above as higher HI. There was no significant difference in the proportion of lower and higher HI participants across the four synergy level conditions, $\chi^2 (3) = 1.14$, $p > 0.76$.

The 52.8% ($n = 186$) of participants whose highest level of education was primary school, lower secondary school, or upper secondary vocational school were classified as ‘lower EL’ and the remaining 47.2% ($n = 166$) of participants were classified as ‘higher EL’. There was no significant difference in the proportion of lower and higher EL participants across the four synergy level conditions, $\chi^2 (3) = 3.31$, $p > 0.34$.

The mean numeracy score was 4.12 ($SD = 0.93$, $Md = 4.25$) and participants were split into two groups based on the median score: 49.7% ($n = 175$) of participants with a numeracy score of less than 4.25 were classified as lower numeracy, and 50.3% ($n = 177$) of participants with a numeracy score of 4.25 and above as higher numeracy. There was no significant difference in the proportion of lower and higher numeracy participants across the four synergy levels, $\chi^2 (3) = 2.12$, $p > 0.54$.

Results

Results for the benefit judgments across the four conditions are displayed in Figure 1. Visual inspection of the results revealed that the majority of the participants made synergistic judgments when the scenarios represented higher and higher-middle synergy levels (63% and 55%, respectively). In contrast, the percentage of synergistic judgments was lower for the lower-middle and lowest synergy level (42% and 38%, respectively).

[Insert Figure 1 about here]

The options that participants selected to represent their judgmental reasoning are displayed in Table 2. The most common lines of reasoning across the whole sample were that (i) the combination would present an additive benefit because the benefits of both factors would sum together (22.7% of all participants), (ii) the combination would present a synergistic benefit because the interaction of the two factors would further increase the health
benefit of both factors (22.4%), and (iii) not sure what the answer would be, so judged the benefit as ‘additive’ at random (16.5%).

Hypotheses 1 and 2. A three-way loglinear analysis (Benefit Judgment x Synergy level x HI) identified a significant two-way interaction between benefit judgment and synergy level, $\chi^2 (3) = 14.96, p < 0.01$, Cramer’s $V = 0.20$, and a two-way interaction between benefit judgment and HI, $\chi^2 (1) = 10.76, p < 0.01, V = 0.17$. The two-way interaction between synergy level and benefit judgment was investigated using separate chi-square tests for each synergy level. This identified that a significantly higher proportion of the participants judged that the lowest level combinations would present a non-synergistic (cf. synergistic) benefit, $\chi^2 (1) = 5.19, p < 0.05$. The difference between the proportion who judged that the lower-middle level combinations would present a non-synergistic (59%) and synergistic (41%) benefit approached significance, $\chi^2 (1) = 2.72, p = 0.09$. There was no significant difference between the proportion of participants who judged that the higher-middle level combinations would present a non-synergistic (45%) and synergistic (55%) benefit, $\chi^2 (1) = 1.09, p > 0.30$.

Significantly more participants judged that the highest level combinations would present a synergistic (cf. non-synergistic) benefit, $\chi^2 (1) = 5.45, p < 0.05$. The two-way interaction between benefit judgment and HI was investigated using separate chi-square tests for the lower and higher HI groups. The lower HI group ($n = 177$) made significantly more 'non-synergistic' judgments (59%) than 'synergistic judgments (41%), $\chi^2 (1) = 6.15, p < 0.05$, whereas the higher HI group (n = 175) made significantly more 'synergistic' judgments (58%) than 'non-synergistic' judgments (42%), $\chi^2 (1) = 4.17, p < 0.05$. The loglinear analysis revealed no main effects or further interactions, $\chi^2$'s (1) $\leq 1.63, ps > 0.65$. Consistent with Hypothesis 1, the analysis revealed that judgments varied according to the synergy-level, with a trend of judging more higher-level synergy combinations to present synergistic
benefits and more lower-level synergy combinations to present non-synergistic benefits. In support of Hypothesis 2, the analysis showed that the proportion of combinations judged to present synergistic benefits was greater for higher (cf. lower) HI participants.²

**Hypothesis 3.** To address Hypothesis 3, the reasoning data for all of the participants that judged the benefit as synergistic \((n = 173)\) was first collapsed into two categories: ‘uncertainty’ (i.e., participants who randomly judged/guessed the benefit to be synergistic) and ‘knowledge’ (i.e., participants who judged the benefit to be synergistic based on any of the other four lines of reasoning, each of which related to acquired or intuitive knowledge). A 2 (reasoning: uncertainty vs. knowledge) x 4 (synergy level: highest, higher-middle, lower-middle, lowest) cross-tabulation analysis revealed a significant difference, \(\chi^2 (3) = 14.94, p < 0.01, V = 0.29\), between the two types of reasoning across the four synergy levels. As shown in Figure 2, the proportion of participants who judged the benefit to be synergistic based on knowledge-based reasoning increased as the combinations increased from lowest to highest on the synergy level hierarchy. This form of data preparation was then repeated and the same 2 (reasoning) x 4 (synergy level) cross-tabulation analysis was conducted for the reasoning data from the participants who judged that the benefit was additive \((n = 151)\). Again, this identified a significant difference, \(\chi^2 (3) = 14.8, p < 0.01, V = 0.31\), between the two types of reasoning across the four levels. As shown in Figure 3, the proportion of participants who judged the benefit to be additive based on epistemic uncertainty was markedly higher for the lowest and lower-middle (cf. higher-middle and highest) level combinations.³ Consistent with Hypothesis 3, there was significantly greater epistemic uncertainty about the health benefits attributable to lower (cf. higher) level combinations.

[Insert Figure 2 about here]

[Insert Figure 3 about here]
**Hypothesis 4.** A three-way loglinear analysis (Benefit Judgment x Synergy level x EL) identified a significant two-way interaction between benefit judgment and synergy level, $\chi^2(3) = 14.54, p < 0.01$. The loglinear analysis revealed no main effects or further interactions, $\chi^2$s (1) $\leq 3.39, ps > 0.28$. Hence, in contrast to Hypothesis 4, the proportion of combinations judged to present a synergistic benefit was not greater for participants with a higher (cf. lower) EL.

**Hypothesis 5.** A three-way loglinear analysis (Benefit Judgment x Synergy level x Numeracy) identified a significant two-way interaction between benefit judgment and synergy level, $\chi^2(3) = 14.53, p < 0.01$. No other main effects or interactions were identified, $\chi^2$s (1) $\leq 2.18, ps > 0.54$. Hence, consistent with Hypothesis 5, numeracy did not affect whether the participants judged that the factor combinations (at four various hierarchical levels) present synergistic health benefits.

**Discussion**

Approximately 60% of our participants were aware or judged that higher level factor combinations can elicit synergistic health benefits, while much fewer participants were aware or judged that lower level combinations elicit such benefits. The reasoning data gathered suggests that when our participants made judgments about the health benefits attributable to lower (cf. higher) level combinations they experienced greater epistemic uncertainty and, consequently, were more likely to judge the benefits as additive. The study indicates that neither education level nor numeracy moderate judgments of synergistic benefits, but that health interest can.

Our results clearly indicate that there is considerable scope to improve lay understanding of synergistic health benefits and, therefore, it is important to consider what factors may play a role in facilitating this understanding. Our finding that individuals with higher ‘health interest’ judged more combinations as synergistic implies that knowledge of
the synergistic health benefits concept could be increased through greater dissemination of
related information. However, we also found that few of the participants with a higher
interest in health reported that their judgments were based on specific knowledge of the
combinations. This suggests that individuals with a higher interest in health may explicitly or
implicitly learn about the synergistic benefits concept (e.g., from health magazines) and are
then more likely to apply this to their benefit judgments in a relatively generic manner. As
explained in Nisbett and Wilson’s (1977) seminal paper on introspective access to cognitive
processes, subjective judgments are often based on a priori causal theories about the extent to
which a particular stimulus (e.g., a factor combination) is the plausible cause of a given
response (e.g., a synergistic benefit), but that individuals are often unaware of the content of
higher order cognitions that facilitate such judgments. Hence, our findings suggest that
individuals may use some form of a priori causal theory of synergistic benefits in their
general judgments of health benefits. That is, an interest in personal health may lead to
exposure to information that explicitly or implicitly suggests that health is maintained and/or
improved via combinations (e.g., diet-and-exercise, fruit-and-vegetables, etc.) and, in turn,
this leads to judgments that most beneficial constituents elicit greater (i.e., synergistic) health
benefits when combined. Moreover, a study by Dawson, Johnson and Luke (2014) indicated
that awareness of certain synergistic health risks (e.g., lung cancer from exposure to radon
and tobacco) may be a function of intuitively constructed mental models that depict the
human body becoming much more vulnerable to harm when exposed to combinations of
hazardous substances. Hence, an a priori causal theory of synergistic health benefits could be
underpinned by the formation of rudimentary mental models that depict the human body
becoming much more resilient to harmful substances and processes when bolstered by the
presence of multiple beneficial factors. One concern this raises is that any psychological
model or theory that leads individuals to assume that all combinations are synergistically
beneficial could lead to judgments in which the health benefits of many non-synergistic combinations are overestimated.

The research on methods for communicating synergistic risks could provide some guidance on the design of intervention that aim to improve understanding of synergistic benefits. For example, while Hampson et al. (1998) found that pie charts were not effective at communicating the synergistic health risk attributable to exposure to radon and tobacco smoke, Dawson et al. (2013) found that using both visualized probabilistic information and pictorial diagrams showing the micro-level interaction of substances inside the human body were effective at communicating the synergistic health risk attributable to using alcohol and tobacco. Dawson et al. argued that the pictorial diagram helped individuals to develop a mental model of the underlying mechanism and the probabilistic information explained the magnitude of the resultant synergistic risk. Clearly, such methods could be empirically assessed for their capacity to improve understanding of synergistic health benefits.

Parties that wish to improve lay understanding of synergistic health risks should also be mindful of other potential challenges. First, research shows that major health behaviours (e.g., exercise, diet, etc.) do not tend to cluster within individuals (Newsom, McFarland, Kaplan, Huguet, & Zani, 2005). Hence, there is little cause to believe that many individuals are already deliberately engaging in behaviours to elicit higher level synergistic benefits. One potential method for addressing this challenge could be to design health promotions that specifically aim to foster ‘transfer cognitions’ in which the psycho-social competencies that an individual develops in one health behaviour domain (e.g., diet planning) facilitate the development of health behaviours in another domain (e.g., exercise planning) (Fleig, Kerschreiter, Schwarzer, Pomp, & Lippke, 2014). Second, campaigns across the world to persuade individuals to increase their fruit and vegetable consumption and to regularly exercise have had limited success. (Godinho, Alvarez, Lima, & Schwarzer, 2014; Guenther,
Dodd, Reedy, & Krebs-Smith, 2006). Therefore, it could be suggested that similar campaigns which attempt to persuade individuals to combine specific dietary/exercise behaviours to elicit synergistic benefits may be even less likely to succeed. However, we suggest that innovative approaches could be employed whereby the onus of identifying, accessing and combining the relevant factors is removed from the individual. For example, healthcare providers (e.g., hospitals) could use and/or endorse recipes that contain foods with synergistic phytochemicals; schools could offer children snacks of specific food combinations (e.g., nut and berries) that enhance cognitive performance; planning authorities could favour the development of exercise routes and cycle paths that travel through green, rather than urban, environments, etc. These “nudging” approaches would be consistent with many contemporary recommendations for the development of environmental, social and economic structures that are conducive to health-enhancing behaviours (e.g., Lewis & Eves, 2012; Marteau, Hollands, & Fletcher, 2012; Thaler & Sunstein, 2008).

This study has some limitations that could be addressed in future research. First, our participants did not judge combinations that produce additive or sub-additive benefits and, therefore, we cannot comment on whether judgments for such combinations would vary relative to those observed in our study. Second, our use of a lay sample prohibits insights into the extent to which ‘domain experts’ (e.g., doctors, nutritionists, etc.) understand synergistic health benefits. Shortcomings in the judgments of synergistic benefits among domain experts could reflect a deficiency in the capacity of the healthcare sector to utilize scientific knowledge of synergistic benefits. Third, caution should be exercised in generalizing our findings beyond our Swiss sample. Moreover, it is possible that awareness of synergistic health benefits may be lower in countries that are less developed than Switzerland because the opportunity to learn about such health concepts may be more limited. Fourth, our study did not explore whether the magnitude of synergistic benefits might have some influence on
benefit judgments. For example, just as the magnitude of synergistic risks can vary (e.g., the risk of a fatal vehicle accident increases 11-fold for a driver who drinks alcohol, while the risk of developing lung cancer increases 25-fold for a smoker who is also exposed to radon in the home; see Dawson, Johnson, & Luke, 2012, 2014), so too can the magnitude of synergistic benefits (e.g., the capacity of green tea to destroy cancerous cells increases 3-fold when combined with curcumin, while the capacity of curcumin to pacify aggressive cancer cells increases 1000-fold when combined with pepper; see Beliveau & Gingras, 2007). Future research might explore whether and how such variations in magnitude are reflected in individual’s benefit judgments. Finally, we obtained data on participant’s cognitive reasoning using a limited range of closed response options. Consequently, this data may not reflect the full range of psychological processes that underlie judgments for a combination’s health benefits. For example, our findings cannot determine the validity of our earlier suggestion that these judgments may be based on a priori causal theories and/or mental models. Future research could explore these possibilities by using alternative techniques, such as ‘thinking aloud’ (e.g., French & Hevey, 2008) to elicit more details of the psychological processes that underlie these judgments and to identify the extent to which individuals are conscious of the methods and reasoning that they employ when judging the holistic effects of combining beneficial factors.

Without further research exploring judgments of synergistic health benefits there will remain an absence of empirical knowledge that can be utilized to inform the design of interventions that effectively improves understanding of this health concept. Consequently, the accumulating scientific knowledge of how people can protect and enhance their mental and physical health by combining specific factors may remain underutilized, resulting in a missed opportunity to improve public health.
References


American Dietetic Association, 106(9), 1371-1379. doi: http://dx.doi.org/10.1016/j.jada.2006.06.002


Footnotes

1. The effect sizes for multifactorial interactions are reported using Cramer’s $V$ and were calculated via cross-tabulations in SPSS. When the $df = 1$ the effect size can be interpreted as low if $\geq 0.10$, medium if $\geq 0.30$, high if $\geq 0.50$; when the $df = 2$ the effect size can be interpreted as low if $\geq 0.07$, medium if $\geq 0.21$, high if $\geq 0.35$; when the $df = 3$ the effect size can be interpreted as low if $\geq 0.06$, medium if $\geq 0.17$, high if $\geq 0.29$ (see Aron, 2012, p. 563).

2. An additional study ($N = 350$) provided corroborative empirical evidence in support of Hypotheses 1 and 2. Please see supporting online information for full details.

3. Cross-tabulation analysis was not performed using the reasoning data for participants who judged the benefit as sub-additive due to the low number of participants ($n = 28$) in this group.
### Tables and Figures

**Table 1.** Hierarchical structure of the eight synergistically beneficial combinations described in the study scenarios

<table>
<thead>
<tr>
<th>Synergy level in a hierarchal scale</th>
<th>Synergy class description</th>
<th>Combinations featured in study</th>
<th>Data source identifying that the combination has synergistic benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Lifestyle combinations</td>
<td>Physical exercise + Nutrient-rich diet</td>
<td>Blair et al. (1996); Gillman et al. (2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical exercise + Natural environment</td>
<td>Mitchell (2013); Pretty et al. (2005)</td>
</tr>
<tr>
<td>Higher-Middle</td>
<td>Food group combinations</td>
<td>Mixed fruits + Mixed vegetables</td>
<td>Jacobs &amp; Temple (2012); Liu (2003; 2004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mixed fruits + Wholemeal foods</td>
<td>Jacobs et al. (2009); Jacobs &amp; Tapsell (2007)</td>
</tr>
<tr>
<td>Lower-Middle</td>
<td>Specific food combinations</td>
<td>Green tea + Turmeric</td>
<td>Manikandan et al. (2012); Xu et al. (2010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tomatoes + Broccoli</td>
<td>Canene-Adams et al. (2004; 2007)</td>
</tr>
<tr>
<td>Low</td>
<td>Specific phytochemical combinations</td>
<td>Quercetin + EGCG</td>
<td>Pignatelli et al. (2000); Tang et al. (2010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resveratrol + Genistein</td>
<td>Rayalam, Della-Fera, &amp; Baile (2011); HemaIswarya &amp; Doble (2006)</td>
</tr>
<tr>
<td>Judgment of the health benefit attributable to the combination</td>
<td>Reasoning underlying judgment</td>
<td>Number (percentage) of participants who employed the line of reasoning</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Synergistic Benefit</td>
<td>The two factors interact and this causes a further increase in the overall health benefits of both factors</td>
<td>79 (22.4%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The two factors interact and this causes a further increase in the overall health benefits of factor X</td>
<td>28 (8.0%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The two factors interact and this causes a further increase in the overall health benefits of factor Y</td>
<td>12 (3.4%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I previously obtained my knowledge about the combination from an information source (e.g., media, educational course, doctor, friend, etc.) and I used this knowledge to arrive at the answer</td>
<td>20 (5.7%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I was not sure what the answer would be, so I selected one of the three options at random</td>
<td>34 (9.7%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total n</strong></td>
<td>173 (49.1%)</td>
<td></td>
</tr>
<tr>
<td>Additive Benefit</td>
<td>I think that the interaction of the two factors would not cause the separate health benefits of either factor to be increased or decreased, but to add together</td>
<td>80 (22.7%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I previously obtained my knowledge about the combination from an information source (e.g., media, educational course, doctor, friend, etc.) and I used this knowledge to arrive at the answer</td>
<td>13 (3.7%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I was not sure what the answer would be, so I selected one of the three options at random</td>
<td>58 (16.5%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total n</strong></td>
<td>151 (42.9%)</td>
<td></td>
</tr>
<tr>
<td>Sub-Additive Benefit</td>
<td>The two factors interact and this causes a decrease in the overall health benefits of both factors</td>
<td>9 (2.6%)</td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>Count</td>
<td>Percentage</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>The two factors interact and this causes a decrease in the overall health benefits of factor X</td>
<td>2</td>
<td>0.6%</td>
<td></td>
</tr>
<tr>
<td>The two factors interact and this causes a decrease in the overall health benefits of factor Y</td>
<td>4</td>
<td>1.1%</td>
<td></td>
</tr>
<tr>
<td>I previously obtained my knowledge about the combination from an information source (e.g., media, educational course, doctor, friend, etc.) and I used this knowledge to arrive at the answer</td>
<td>0</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>I was not sure what the answer would be, so I selected one of the three options at random</td>
<td>13</td>
<td>3.7%</td>
<td></td>
</tr>
<tr>
<td><strong>Total n</strong></td>
<td><strong>28</strong></td>
<td><strong>8.0%</strong></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Participant’s judgments of the benefits attributable to combinations at four synergy levels ($N = 352$).
Figure 2. Participant’s reasoning (knowledge-based vs. epistemic uncertainty) for judgments that the benefit attributable to the combination (at the four synergy levels) was synergistic ($n = 173$).
Figure 3. Participant’s reasoning (knowledge-based vs. epistemic uncertainty) for judgments that the benefit attributable to the combination (at the four synergy levels) was additive ($n = 151$).